

Safety Issues in Fossil Utility and Industrial Steam Systems

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This report presents results of recent surveys of safety issues in the fossil utility and industrial steam systems. The boiler problem statistics are from the recent publications by the National Board [1, 2] and the problems with other components are summarized, based on our experience.

The U.S. National Board of Boiler and Pressure Vessel Inspectors reports that 296 power plant boiler-related accidents (including 56 injuries and seven deaths) occurred in 2001 [1]. Over a ten-year period (1992 – 2001), there was a combined total of 23,338 accidents, including 127 fatalities and 720 injuries, reported for all power boilers, water and steam heating boilers, and unfired pressure vessels. The highest number of accidents occurred in 2000 (2,334) and the lowest number (2,011) occurred in 1998. However, the greatest number of both fatalities and injuries occurred in 1999. The total number of deaths increased 40 percent during the time period from 1997 to 2001 as compared to 1992 to 1996 [2].

While the numbers may fluctuate each year, one measure of how the industry is faring can be found in the injury-per-accident ratio. Since 1992, this ratio has ranged from one injury for every 99 accidents in 2000 (the safest year) to one injury for every 19 accidents in 1999 (the most dangerous).

The average ratio of injuries to accidents from 1992 to 2001 is one injury for every 32 accidents [2].

Of the 23,338 incidents reported to the National Board from 1992 to 2001, 83 percent were a direct result of human oversight or lack of knowledge (low water condition, improper installation, improper repair, operator error, or poor maintenance). Human oversight and lack of knowledge were responsible for 69 percent of the injuries and 60 percent of the recorded deaths [2].

Table 1 summarizes all of the accidents reported to the National Board in 2001 for several types of pressure vessels [1] and Table 2 gives details on the causes of the power boiler incidents. These figures underscore the importance of safety issues in fossil utility and industrial steam cycles as well as addressing damage mechanisms such as fatigue and corrosion, furnace explosions, fire hazards, handling coal and other fuels, electrical systems, lifting, transportation, and human errors.

What makes a damage mechanism a safety issue is a combination of an undetected slow-acting damage mechanism with a critical load (stress or stress intensity) that leads to a **break before leak**, a **break before vibration**, or some other warning. The problems considered in this paper can be characterized as low frequency, high impact events. Except for the deaerator weld corrosion fatigue cracking, for which root causes are not known, the problems are well understood and the engineering solutions and inspection and monitoring methods are available [3 to 17]. It is mostly a question of the application of this knowledge.

Table 1: Summary of accidents occurring in 2001 for various types of pressure vessels [1]

Type of Vessel	Accidents	Injuries	Fatalities
Power Boilers	296	56	7
Heating Boilers: Steam	1091	0	1
Heating Boilers: Water (includes hot water supply)	631	10	0
Unfired Pressure Vessels	201	18	4
Totals:	2219	84	12

Note: National Board survey based on a 75% response rate for National Board jurisdictional authorities and a 41% response rate from authorized inspection agencies. The total number of surveys mailed was 89, with a 64% response rate overall.

Table 2: Summary of incidents occurring in power boilers in 2001 [1]

Cause of Incident	Accidents	Injuries	Deaths
Safety Valve	4	0	0
Low-Water Condition	161	3	0
Limit Controls	8	0	0
Improper Installation	2	0	0
Improper Repair	1	0	0
Faulty Design or Fabrication	2	0	0
Operator Error or Poor Maintenance	82	50	7
Burner Failure	29	2	0
Unknown/Under Investigation	7	1	0
Subtotal	296	56	7

Table 3 lists critical steam cycle components, their damage mechanisms, and influences. It also gives information on the experience with destructive failures and their dollar impact [18, 19].

WEAKNESSES IN THE SAFETY CONTROL

An example of good safety control is the nuclear power industry where there have been extensive efforts in cycle and component design, development of material properties, component testing, field monitoring, and information exchange. Several organizations, including the Nuclear Regulatory Commission, Institute for Nuclear Power Operation, and Electric Power Research Institute, helped to achieve the current state of nuclear safety.

Such extensive research and organizational support does not exist for the fossil utility and industrial steam cycles. Based on our experience with root cause and failure analysis, the following weaknesses in the industry's handling of the safety issues can be identified:

- Lack of knowledge and/or its application by designers, operators, and inspectors; particularly in industrial steam systems
- Only artificial determination of the root causes. An estimated 40% of the root causes are not correctly determined
- Missing material data, particularly on creep – fatigue and fatigue – corrosion interactions

- Poor understanding of the effects of water and steam chemistry and operation of equipment (cycling, transients, etc.) by investigators and operators

Examples of the deficiencies include a lack of information exchange on safety issues in industrial systems, unknown root causes of deaerator weld cracking, insufficient inspection requirements (only visual inspection of some critical piping, etc.), unknown fundamental mechanisms for fatigue, corrosion fatigue, and stress corrosion.

RECOMMENDATIONS

1. Equipment operators, inspectors, insurance companies, and designers should all address the safety issues.
2. The most effective safety control improvement would be through a similar system used in nuclear safety. A distinguished organization such as ASME and API should assume the responsibility.
3. An effective approach to achieve safety in a steam system includes training and a safety or condition assessment audit (see www.mindspring.com/~jonasinc/condition_assessment.htm).

Table 3: Critical steam components, their damage mechanisms, and influences

Component ¹	Damage Mechanism ²	Major Influences ³	Destructive Failures ⁴	\$ Impact ⁵
Steam Piping [6 to 8]	Creep	Welds, temperature, time	Yes	10 ⁷
	LCCF, LCCF	Temperature changes		
	Carbon steel graphitization	Temperature and time	Yes	
Drums and Headers [6 to 8]	LCCF, LCCF, SCC	Temperature cycling, design, water chemistry	No	10 ⁷
Boiler Tubes [10]	LCCF (20 others)	Water chemistry, cycling, heat flux, etc.	Yes	10 ⁶
Feedwater and Wet Steam Piping [9, 14 to 16]	FAC	Design, water chemistry	Yes	10 ⁷
	Cavitation	Design, operation	Yes	
	SCC	Residual stress, chemistry	No	
	CF, LCCF	Weld quality, water chemistry, temperature changes	No	
Deaerator, Flash Tank, Hot Water and Steam Vessels - Welds [9, 17]	CF, SCC	Design (water piston), residual welding stress, operation, water chemistry	Yes	10 ⁷
LP Turbine Rotors and Disks [9, 11 to 13]	SCC	Design stresses, temperature ^a , high-strength steel, steam chemistry	Yes	10 ⁷
	CF	Steam chemistry, design, vibration	No	
LP Turbine Blades [9, 11 to 13]	CF, SCC	Steam chemistry, design vibration, pitting, erosion, high-strength steel	No	10 ⁶
HP/IP Turbine Rotors [8, 11 to 13]	LCCF	Cycling, inclusions, fatigue design	Yes	10 ⁷
Turbine [11 to 13]	Destructive Overspeed	Steam chemistry (boiler carryover), sticking valves	Yes	10 ⁷ - 10 ⁸
Turbine [11 to 13]	Rubbing	Steam chemistry, deposits, thrust bearing, expansion	Yes	10 ⁷

- Numbers in [] are References
- CF - Corrosion Fatigue, LCF - Low Cycle Fatigue, LCCF - Low Cycle Corrosion Fatigue, SCC - Stress Corrosion Cracking, FAC - Flow-Accelerated Corrosion
- Age influences the degree of damage for all issues except the last two
- At least one destructive failure during the last 30 years
- Lost production and repairs per one event. The cost of lost production is typically much higher than the loss from repairs with a ratio up to 10:1

- A "Safety Expert System"—a software package, which could be customized for each steam cycle, should be developed.
- ASME Boiler and Pressure Vessel Code sections dealing with boiler and piping inspections and defect evaluations need to be updated and more specific guidance for NDT and fitness for service evaluations should be provided.

REFERENCES

- 2001 National Board Incident Report. U.S. National Board of Boiler and Pressure Vessel Inspectors.
- "The Numbers are in ... Ten Years of Incident Reports Underscore Human Error as Primary Cause of Accidents." *National Board Bulletin*. Summer 2002.
- G. Celedonia, et al. "Make Safety Performance Part of 'Business as Usual'." *Power*, January/February 2001.
- Fitness for Service*. API Recommended Practice 579, January 2000.

5. *Handbook of Loss Prevention*. Allianz Versicherungs-AG, Berlin/Munchen 1978.
6. *Corrosion in Power Generating Equipment*. Editors Markus O. Speidel and Andrejs Atrens. Plenum Press, New York, 1984.
7. *Fatigue and Fracture, Volume 19*. ASM Handbook, ASM International, Materials Park, OH, 1996.
8. R. Viswanathan. *Damage Mechanisms and Life Assessment of High-Temperature Components*. ASM International, Metals Park, OH, 1989.
9. *Low Temperature Corrosion Problems in Fossil Power Plants – State of Knowledge*. EPRI, Palo Alto, CA. To be published.
10. B. Dooley and W. McNaughton. *Boiler Tube Failures: Theory and Practice, Vol. 2: Water-Touched Tubes*. Electric Power Research Institute, Palo Alto, CA, 1996.
11. T. McCloskey, R. Dooley, and W. McNaughton. *Turbine Steam Path Damage: Theory and Practice, Vol. 2: Damage Mechanisms*. Electric Power Research Institute, Palo Alto, CA, 1999.
12. O. Jonas. "Corrosion and Deposition Problems in Steam Cycle." *Power Station Chemistry 2000 Conference*. May 15-16, Queensland, Australia.
13. O. Jonas and B. Dooley. "Major Turbine Problems Related to Steam Chemistry: R&D, Root Causes, and Solutions." Paper presented at 5th International Conference on Cycle Chemistry in Fossil Plants, EPRI, Charlotte, NC, June 10-12, 1997.
14. B. Chexal, et al. *Flow-Accelerated Corrosion in Power Plants*. Electric Power Research Institute, Palo Alto, CA, 1996. TR-106611.
15. O. Jonas. "Alert: Erosion-Corrosion of Feedwater and Wet Steam Piping." *Power*, February 1996.
16. O. Jonas. "Erosion-Corrosion of PWR Feedwater Piping - Survey of Experience, Design, Water Chemistry, and Materials." *Report for U.S. Nuclear Regulatory Commission*, NUREG/CR-5149, ANL-88-23, March 1988.
17. O. Jonas. "Deaerators: An Overview of Design, Operation, Experience, and R&D." *Proc. of the American Power Conference*, Vol. 49, A. 979, Ill. Institute of Technology, 1987.
18. *Cost of Corrosion in the Electric Power Industry*. EPRI. Palo Alto, CA. October 2001. Report 1004662.
19. B. Syrett, et al. "Cost of Corrosion in the Electric Power Industry." *Materials Performance*. Vol. 41, No. 3. March 2002.